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Concept of Operations for Integrated Intelligent Flight Deck Displays and Decision Support Technologies

*Randall E. Bailey, Lance J. Prinzel III, Lynda J. Kramer, and Steve D. Young
Langley Research Center, Hampton, Virginia*

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Table of Contents

1. PURPOSE AND SCOPE	1
1.1 Purpose	1
1.2 Scope	2
2. ASSUMPTIONS.....	4
2.1 Application Domain	4
2.2 Technology Readiness Level	4
2.3 Crew Complement and Aircraft Operations.....	4
2.4 Flight Crew Training and Experience	4
2.5 Technology Insertion for NextGen	4
2.6 NextGen Infrastructure (Circa 2020-2025).....	5
2.7 Flight Deck “Baseline” Equipage and Configuration	5
2.8 Impacts on ANSP and other NAS Users.....	6
2.9 Certification and Operational Approval.....	6
3. CHARACTERISTICS OF THE SYSTEM	7
3.1 Description of desired changes	7
3.2 System Overview	8
3.3 Description of the proposed system	8
3.3.1 Head-Worn Displays.....	8
3.3.2 Comprehensive High Integrity Information Processing	9
3.3.3 Decision Support Functions.....	12
3.3.4 Visual Display Enhancements	14
3.3.5 Communicative Interface Enhancements	15
3.4 Modes of operation.....	17
3.4.1 EVO	18
3.4.2 EVC.....	19
3.4.3 NextGen	20
4. OPERATIONAL SCENARIOS.....	22
5. CONCLUDING REMARKS	28
6. REFERENCES.....	29
APPENDIX A – ASSUMED NEXTGEN ENVIRONMENT	32
Background	32
NextGen Flight Deck “Baseline”	32
NextGen Operations and Ground Infrastructure (Circa 2020-2025)	35
Push Back, Taxi, and Departure	35
Descent and Approach	36
Landing, Taxi, Arrival	38

List of Figures

FIGURE 1: FLIGHT DECK SYSTEM SPIRAL R&D PROCESS	2
FIGURE 2: SPATIALLY-INTEGRATED FLIGHT DECK DISPLAY CONCEPT	9
FIGURE 3: INFORMATION PROCESSING SCHEMATIC SUPPORTING INTEGRATED ALERTING AND NOTIFICATION	11
FIGURE 4: MISSION REHEARSAL TOOL CONCEPT ILLUSTRATION	14
FIGURE A- 1: BOEING 787 - "NEXTGEN" BASELINE FLIGHT DECK	33
FIGURE A- 2: NEXTGEN-BASELINE MULTI-FUNCTION DISPLAY LAYOUT	34
FIGURE A- 3: AIRPORT MAP VIEW - NEXTGEN BASELINE	34
FIGURE A- 4: PRIMARY FLIGHT DISPLAYS - NEXTGEN BASELINE	35
FIGURE A- 5: KEY GROUND INFRASTRUCTURE AND AVIONICS FOR NEXTGEN SURFACE OPERATIONS (CIRCA 2020)	36
FIGURE A- 6: KEY GROUND INFRASTRUCTURE AND AVIONICS FOR NEXTGEN DESCENT AND APPROACH ...	38

Nomenclature

3-D	Three Dimensional
4-D	Four Dimensional
4DT	4-D Trajectory
AC	Advisory Circular
AD	Application Domain
ADS-B	Automatic Dependent Surveillance-Broadcast
ANSP	Air Navigation Services Provider
ATIS	Automated Terminal Information System
BTV	Better Than Visual
CD&R	Conflict Detection and Resolution
ConOps	Concept of Operations
CPDLC	Controller-Pilot Data Link Communications
DA	Decision Altitude
DDS	Displays and Decision Support
DH	Decision Height
EFB	Electronic Flight Bag
EFVS	Enhanced Flight Vision Systems
EGPWS	Enhanced Ground Proximity Warning System
EHM	External Hazard Monitor
EICAS	Engine Indication and Crew Alerting System
ETA	Estimated Time of Arrival
EV	Enhanced Vision
EVC	Enhanced Visual Capabilities
EVO	Equivalent Visual Operations
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FANS	Future Air Navigation System
FAR	Federal Aviation Regulation
FIS-B	Flight Information Service-Broadcast
FMS	Flight Management System
GLS	Global Navigation Satellite System Landing System
HUD	Head-Up Display
HWD	Head-Worn Display
IIFD	Integrated Intelligent Flight Deck
ILS	Instrument Landing System
MAP	Missed Approach Point
MDA	Minimum Descent Altitude
MASPS	Minimum Aviation System Performance Standards
MrT	Mission Rehearsal Tool
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
ND	Navigation Display
NextGen	Next Generation Air Transportation System
NOTAM	Notice to Airman
RDT&E	Research, Development, Test and Evaluation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RVR	Runway Visual Range
SV	Synthetic Vision
SVS	Synthetic Vision Systems
TCAS	Traffic Alert and Collision Avoidance System
TERPS	Terminal Instrument Procedures

TIS-B	Traffic Information Service-Broadcast
TMA	Terminal Maneuvering Area
US	United States
VFR	Visual Flight Rules
VS	Vision System
WxR	Weather Radar

1. Purpose and Scope

1.1 Purpose

Methods for piloting and managing flights will change dramatically over the coming decades. While many aircraft may have the same general configurations, their trajectories may be defined in distinctly new ways, including complex, frequently-changing specifications providing optimal efficiency, minimal environmental impact, and flight relative to other aircraft. Similarly, pilots' tasks may expand to include collaboration and negotiation with other aircraft and with air traffic controllers, and may require managing large disparate sets of information to support a wide range of decisions made both individually and collaboratively. Current projections also prescribe an increased use of automation, much of which will need to interact with, and support, the cognitive activities of pilots and air traffic controllers. To simultaneously achieve target levels of performance and safety, these changes require systematic study, and design of, new technologies and new operating procedures. If addressed early in design, synergistic solutions may enhance safety while also facilitating goals for increased capacity and reduced environmental impact; conversely, if addressed too late, safety considerations will likely serve as constraints on operations. In other words, as new operating concepts advocate changes to current operations, rigorous systematic research must address to what extent safety is maintained, improved, or potentially compromised.

NASA's Integrated Intelligent Flight Deck (IIFD) research plan (see http://www.aeronautics.nasa.gov/nra_pdf/iifd_tech_plan_2009.pdf) embodies one approach to this required 'rigorous systematic research.' The approach explores the design space in a systematic manner referred to as a spiral R&D process that is based upon foundational research findings as well as lessons-learned from evaluations of hypothesized system-level concepts (Figure 1).

The purpose of this document is to fulfill one of the needs represented in the upper left quadrant of Figure 1; namely, to hypothesize a Concept of Operations (ConOps) for Display and Decision Support (DDS) aspects of a flight deck system. The other need called out in Figure 1 is for a ConOps for human-automation integration. This ConOps is documented separately.

Each ConOps serves as:

- (1) a driver for discipline-specific and foundational research on relevant topics;
- (2) the basis for prototyping and evaluations in high fidelity simulation and flight facilities to resolve, and uncover issues, and
- (3) an enabler to develop system-level evaluation test-beds that allow for such studies to examine a parametric design space over the long-term; this capability is critical as it is unlikely that the design of such complex systems can be sufficiently informed through physical testing of single 'point designs.'

In Figure 1, project milestones are shown indicating a nominal two-year cycle in the spiral process to track progress. Within each cycle, a concept definition (i.e. ConOps) phase is followed by a development phase, and then an evaluation phase. Subsequent two-year periods may either refine the previous concept, switch to an alternate concept, or declare the research complete, at which time the project can move on to another challenge. During each concept definition phase, research results and developments are considered, resulting in a design informed by state-of-the-art. Likewise, following each concept evaluation phase, results are used to re-assess, or learn, the degree to which research issues are resolved or uncovered.

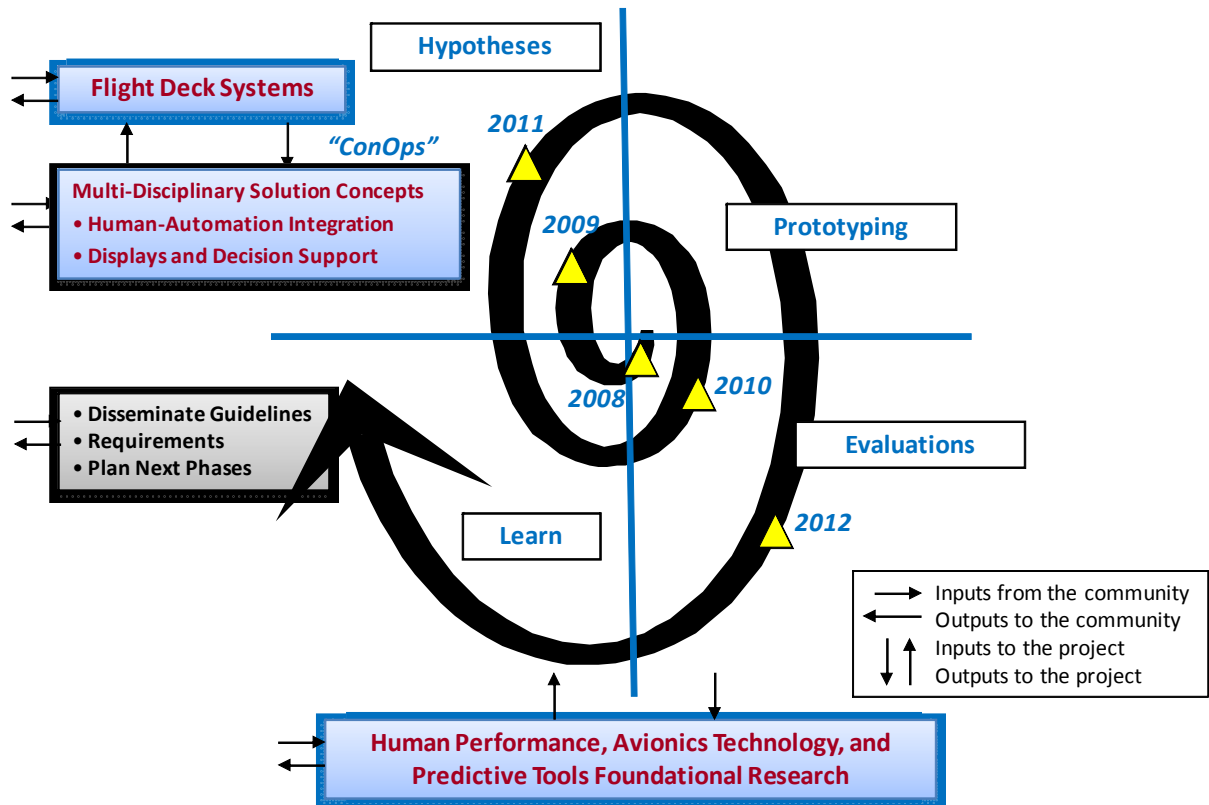


Figure 1: Flight Deck System Spiral R&D Process

1.2 Scope

The scope of this ConOps is established by first selecting an Application Domain (AD). The AD represents the design space for a system as constrained by a particular set of end-user requirements. For flight deck systems, the AD is considered a multi-dimensional design space spanning: mission, operating environment, target level of performance, crew, vehicle, and equipment.

The AD initially selected for IIFD research is the NextGen Terminal Maneuvering Area (TMA). The TMA is chosen to focus on flight deck operations with traditionally the greatest risk exposure, complexity, and operator workload. An additional benefit of

selecting this domain is the degree of collaboration and synergy it enables with multiple research focus areas within NASA's Airspace Systems Program.

A ConOps is a general description of how a system will operate. This DDS ConOps posits a mid- to far-term solution concept for best supporting human decision making in the flight deck during terminal area operations. The DDS ConOps is organized into three sections: Assumptions; System Characteristics; and Operational Scenarios.

In summary, this DDS ConOps is developed to allow demonstrations that expose the benefits and barriers to transformative changes in flight deck displays and decision support functions and to evolve methods for the design and evaluation of such concepts. The iterative R&D approach begins by positing solution concepts herein that are then to be tested under both nominal and off-nominal conditions in evaluation testbed(s).

2. Assumptions

This ConOps is based upon several assumptions regarding the future air transportation system and the vehicles operating within it. These are described in the following subsections.

2.1 Application Domain

The technology and operating concepts within this ConOPS are targeted toward TMA operations, both airborne and on the surface. However, it is assumed that these concepts and technologies will in many cases apply, or generalize, to operations outside the TMA.

2.2 Technology Readiness Level

The technology and operating concepts can be advanced to a Technology Readiness Level (TRL) of seven (TRL7) within ten years (circa 2019) with research and development through the TRL levels in the intervening years by NASA and/or others in the industry. TRL 7 requires “system prototype demonstration in an operational environment.” (DoD Defense Acquisition Guidebook, 2006; Graettinger et al, 2002). Although not explicit in the definition, it is assumed that operational aspects (e.g., crew roles and procedures) must also be demonstrated to achieve TRL7.

2.3 Crew Complement and Aircraft Operations

The ConOPS and associated technology assumes two-crew, commercial and business fixed-wing aircraft operations. This is not to imply that these concepts and technologies are not applicable to other domains; they, in fact, may be. However, proof for this general applicability is not given herein.

2.4 Flight Crew Training and Experience

Because of the assumed domain of aircraft and operations, all pilots in this domain of operations are assumed to hold an Airline Transport Pilot certificate, or equivalent.

It is further assumed that pilots are US-trained and native-English speakers. The extendibility of these concepts and technologies to other cultures and languages are considered and desirable. However, proof for this generality is not given herein.

2.5 Technology Insertion for NextGen

The vast majority of aircraft which will operate in NextGen ten to twenty years hence are assumed to have been already built and almost all have already been designed. Very few new designs that emerge over the intervening years will have evolved to TRL 7. As such, the displays and decision support concepts described herein are tailored toward the

governing principles for accelerating NextGen equipage (FAA, 2009) wherever possible and practical. These principles include:

- Equipage and associated capabilities are developed to maximize operational benefits for the specific locations or airspace that require a higher performance level in order to elevate system performance and to satisfy demand.
- Operations, performance requirements and avionics solutions are globally harmonized to ensure maximum benefits to operators who fly internationally.

As a result, this ConOps leverages and maximizes the benefits of using and extending existing equipage. Exceptions to this philosophy will be noted as appropriate and necessary where the safety or performance benefits of new or novel approaches significantly outweigh the costs associated with retrofit or overhaul of existing operations and operational precepts.

In this case, it is assumed, and expected, that policies and constraints may be placed into effect whereby equipage and associated capabilities that yield higher performance levels will be required in order to operate within certain airspace classes and at certain peak traffic periods to support higher levels of traffic capacity. These policies and constraints may provide incentives for the modifications to existing equipment or the installation of new equipment; that is, if the operator wants the freedom to globally operate without time or space restrictions due to traffic and weather congestion, equipage for higher performance and autonomy may be required.

2.6 NextGen Infrastructure (Circa 2020-2025)

The flight deck display and decision support technologies and operating concepts described herein are assumed to function in concert with a ground- and space-based infrastructure as forecasted for the 2020-2025 timeframe for NextGen. This infrastructure is described in (FAA, 2009) and summarized in Appendix A.

2.7 Flight Deck “Baseline” Equipage and Configuration

The technologies, functions, and operating concepts described in Section 3 are extensions, or modifications, to an assumed “baseline”. This baseline is generally reflective of the Boeing 787 aircraft, but is also representative of capabilities existing on other state-of-the-art commercial and business aircraft (e.g., the Airbus A-380, and the Gulfstream G-650).

Such a baseline class of aircraft is assumed since they represent the present state-of-the-art and, in all likelihood, will still represent the most technologically advanced commercial flight decks in service in the 2019 time frame. As such, many of the anticipated flight deck needs to support NextGen have been considered and included in the design of the aircraft. Display and decision support concepts identified in the following seek to improve upon this baseline by filling capability gaps and removing safety vulnerabilities to better support NextGen operations and the needs of the flight crew. It is assumed that if these concepts can demonstrate safety and performance

advantages when compared to, and extended from, this baseline, similar or even greater advantages can result when applied to other vehicle classes operating in NextGen.

A brief description of the assumed baseline flight deck system is given in Appendix A.

2.8 Impacts on ANSP and other NAS Users

This ConOps is primarily associated with flight deck technologies, functions, operational procedures, and the role of the flight crew. Of course, the role of the Air Navigation Service Providers (ANSPs), Air Carrier Dispatchers, and other National Airspace System (NAS) participants must also be considered and reconciled with any new flight deck technology or procedure. It is assumed that the roles of these participants are primarily being conceived by others (e.g., JPDO, FAA, and NASA's Airspace Systems Program); and as such, coordination is necessary throughout IIFD's spiral R&D process.

2.9 Certification and Operational Approval

These future concepts may lead to requirements for new or revised rules, regulations, and/or operating standards for certification and operational approval. The impacts of these changes to regulations or policies are not presently considered in this ConOps; however, they would be tracked as part of the R&D process.

3. Characteristics of the System

This ConOps describes display and decision support technologies and operating concepts that can proactively overcome aircraft safety barriers that would otherwise constrain the full realization of the Next Generation air transportation system (NextGen).

This concept asserts that achieving NextGen's goals requires new technology and procedures – not only on the ground-side – but also in the flight deck. As described in the following, to achieve the safety and operational benefits promised by NextGen, a new flight deck system concept emerges – Better Than Visual (BTV) operations.

3.1 Description of desired changes

The desired changes to achieve BTV both are operational and technological.

BTV operations are comprised of three synergistic components:

1. Equivalent Visual Operations Capability
2. Enhanced Visual Capability
3. NextGen Operations Capability

First, new flight deck technologies are identified which enable an Equivalent Visual Operations (EVO) capability whereby Visual Flight Rules (VFR)-like procedures may be used in any visibility condition by providing the required cues via an electronic means within the cockpit when visual 'out-the-window' cues are otherwise obscured by lighting or atmospheric conditions. This capability largely eliminates the need for developing an entirely new set of operating rules or procedures for NAS users.

Second, an Enhanced Visual Capability (EVC) is created by applying technologies that can provide an additional level of safety, above and beyond that of present-day VFR operations. EVC mitigates current limitations by providing the capability for the crew to see-and-avoid or mitigate hazards which are otherwise "invisible" to the flight crew. These include, for example, weather-related hazards (e.g., wind shear, clear air turbulence, and wake vortices), restricted airspace boundaries, and closed or unsuitable runways and/or taxiways.

Third, and finally, technologies and capabilities are identified to support new and emerging NextGen operating concepts such as trajectory-based operations; in particular, those that present unique challenges on the flight deck. This facet of the concept identifies these challenges and posits mitigating technologies and operating paradigms for the flight deck – all based upon the BTV premise.

3.2 System Overview

The goal of BTV is to achieve the operational tempos and capacity while also improving upon the safety record of today's VFR flight operations. These goals are met while operating within the operational paradigms associated with NextGen, regardless of visibility conditions.

BTV is enabled by new operating methods, flight deck technologies, and associated systems and subsystems; as described in the following.

3.3 Description of the proposed system

Five areas of significant change are needed to enable the BTV operational concept. Although they are separately addressed in the following, their functionality is clearly intermingled.

3.3.1 Head-Worn Displays

A new display – an unobtrusive, very lightweight head-worn display (HWD) with an integrated head-tracking system – is envisioned (Figure 2) as necessary to enable BTV. The small footprint for the display and tracker creates an easy retrofit installation.

This HWD provides three principle benefits for BTV:

1. Spatially-Integrated Display Concepts: Combinations of aircraft-reference and earth-reference symbology and imagery will create “spatially-integrated” display concepts where the location of the displayed information provides significant cues for the pilot. For instance, “scene-linked symbology” provides symbolic references located such that they overlay a real-world position that moves and transforms as though they were actual objects in the world (e.g., Foyle, McCann, and Shelden, 1995). The technique of symbology scene-linking facilitates efficient cognitive processing of both the symbology and the environment, and mitigates problems of attentional tunneling and symbology fixation (e.g., Foyle et al, 1996).
2. Reduced Clutter Visual Displays: The coupled HWD provides significant reductions in visual display clutter by providing increased display area. Instead of being limited to the finite display space on the instrument panel, the unlimited field-of-regard HWD tracking and display system can utilize the entire three-dimensional volumetric space around the pilot, as appropriate and necessary. Binocular optics also add the potential to use stereoptics for decluttering and more effective information presentation (Parrish, Williams, and Nold, 1994; Wickens, Todd, and Seidler, 1989; Reising and Mazur, 1990).
3. Unlimited Field-of-Regard, Head-Up Information: The coupled HWD enables an unlimited field-of-regard capability for “head-up” information. Unlike a Head-Up Display (HUD), with its limited, fixed, forward field-of-view (FOV), head-up information can be displayed in any aspect or direction, without display

minification (i.e., conformally). The display enables an augmented reality concept (i.e., spatially-integrated symbology and imagery) and also, provides an electronic means of representing the external world, and other required flight references, in an identical manner to what is provided during current-day visual conditions; that is, the ability to look outside the aircraft through “virtual windows” to the world.



Figure 2: Spatially-Integrated Flight Deck Display Concept

3.3.2 Comprehensive High Integrity Information Processing

The NextGen operating environment and emerging operational concepts depend upon and benefit of a “Net-centric” information sharing environment, where each aircraft is a node on a vast information network. The advantage of this envisioned environment is that the “whole” can be significantly smarter and more aware than just a single individual entity. The challenge is to manage the information available from this network without overloading or underwhelming the operators/users. The goal should be to provide the crew with the information they need, when they need it, and with a quality they can trust.

Information processing technologies and techniques are critical to this goal. This processing is conducted “behind the glass” to off-load the crew, bringing the crew in the loop only as necessary to alert, notify, or otherwise engage the crew. Data integrity checking and data extraction processing (i.e., “culling”) is critical.

Data will come from on-board and off-board sources in the “net-centric” NextGen environment. A schematic diagram is drawn in Figure 3 to illustrate these processes.

- The aircraft state data in the NextGen environment will not be significantly different than today’s environment, with the exception that the performance levels should be significantly higher to support higher routine levels of required navigation performance (e.g., RNP 0.1 or better). Aircraft state data include such parameters as airspeed, altitude, and positioning information (derived from kinematic, inertial, and ground-based and satellite-based navigation aids). Health-

monitoring systems are present to assist the data processing function and to serve as an independent means of verifying the health and status of the aircraft systems.

- On-board sensors provide context-relevant information regarding the external environment. New sensor technologies, such as those used for wake vortex detection for which limited capability exists today, are not expected to achieve TRL 7 within the next 10 years (per the assumptions of Section 2). However, there are multiple sensing capabilities and performance improvements that are expected to mature in this timeframe which can provide significant enhancements. These include advances in weather radar (WxR) capabilities, and Enhanced Vision (EV) imaging sensor capabilities (e.g., Forward Looking InfraRed and millimeter wave radar sensing).
- In the NextGen environment, the propagation and prominence of data-link information services will significantly increase. Traffic Information Services-Broadcast (TIS-B), Flight Information Services (FIS-B), Aircraft Communications Addressing and Reporting System (ACARS), and Automatic Dependent Surveillance-Broadcast (ADS-B) in/out services will be pervasive. Initially, ACARS messaging will support the transmission of ANSP services such as routing and negotiation functions for arrival and departure functions and surface operations. The broadcasting of in-flight weather observations will begin whereby turbulence levels and winds aloft will be reported to allow other users to optimize routing and flight efficiency. ADS-B information will be augmented with aircraft intent information to support improved functionality and situation awareness for all users. Aeronautical information (e.g., Notices to Airmen) and other ground-based services and forecasts will be provided by a new data link service (perhaps as part of FIS-B) (see, for example, RTCA DO-308).
- In the NextGen environment, the prominence of on-board databases will grow and their accuracy and integrity will increase (see, for example, RTCA DO-272B and DO-276B). This information will consist of terrain, airport features, navigation aids, and obstacles, all with world-wide coverage and with high integrity and accuracy. Onboard and up-to-date databases will also include air carrier standard operating procedures and checklists, maintenance logs and procedures, and enroute and terminal area procedures, routes, and charts. Updates to such information sets will be provided at nearly contemporaneous rates (i.e., near real-time) via data link services both in-flight and at the gate.

To enable the effective employment of these information sets by the flight crew, the separate data sources are processed to achieve the following functions.

- Integrity: Data from disparate sources are compared for consistency to determine their consistency and integrity. Data that does not possess sufficient accuracy, reliability, and/or integrity will be flagged to the attention of the flight crew, as necessary and appropriate, or automatically discarded and not used.
- Culling and Extracting: Data which are peripheral to the primary crew tasks or significantly less important and only serve to confuse the user or data processes

are culled. Data extraction processing (e.g., data mining) are conducted “behind the glass” to identify data source reliability and data of emerging significance and importance. This function provides for ‘context-relevant’ information provision.

- **Integration:** Data integration is the combination of data from separate sources wherein the data sources remain evident to the user in the final product. In this manner, the user retains knowledge of and can readily made comparisons from the separate sources for improved understanding. However, careful design of the integration process must be made to prevent an unintended loss of understanding. Per this definition, integration can also be thought of as ‘overlying’ information from multiple sources.
- **Fusion:** In contrast to integration, data fusion is the combination of data from separate sources wherein the data sources are no longer evident to the user in the final product. The final data product is designed to be readily understandable and usable, and ideally the user does not need to know the source or the processes used in the creating the final product. The goal of data fusion is to create an improved data product that takes advantage of complimentary characteristics of multiple sources. A good example of fusion in today’s systems is the ‘fusion’ of GPS and inertial navigation information through Kalman filtering techniques.

For BTV, these data processing functions primarily, but not exclusively, support two functions: (1) direct display to the flight crew (i.e., “Visual Displays”) and (2) data to support automation functions which assist the flight crew (i.e., “Decision Support Functions”). An Integrated Alerting and Notification (IAN) capability is envisioned that would provide both of these functions for BTV operations.

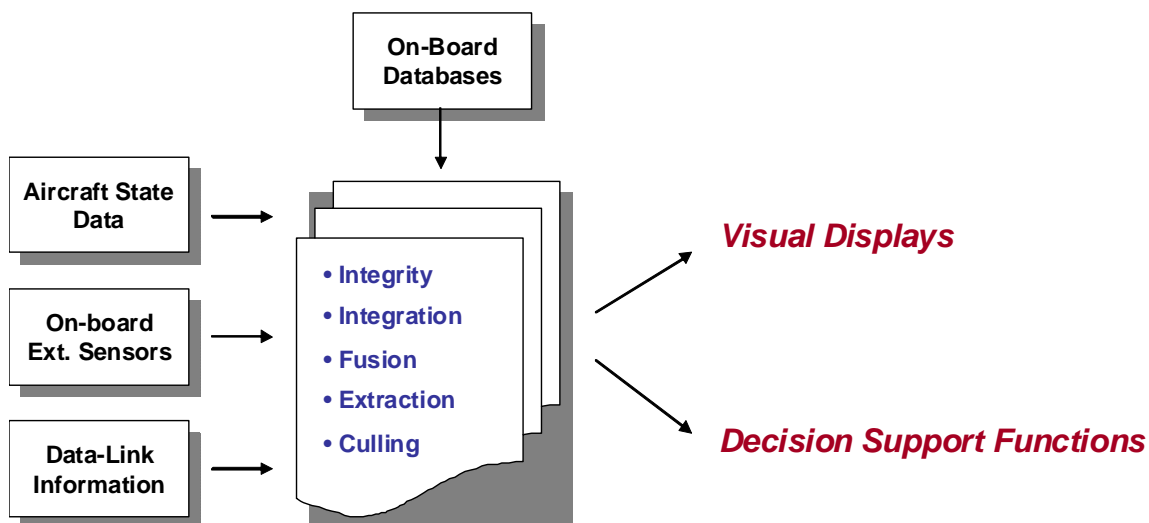


Figure 3: Information Processing Schematic Supporting Integrated Alerting and Notification

3.3.3 Decision Support Functions

Decision support functions provide the flight crew with information and attendant guidance to react to and initiate changes in the flight plan or trajectory as necessary and appropriate. These functions may modulate the crew's attention engagement, awareness, and workload, both explicitly and implicitly, depending on the situation. For BTV, these decision support functions are tailored to the requirements of a NextGen 4D trajectory-based operation. Depending on the pace of technology maturation, all of the decision support functions described below may become part of an Integrated Alerting and Notification (IAN) function. However, it remains to be determined to what degree these functions should be 'integrated' to achieve BTV objectives.

An External Hazard Monitor (EHM) function is provided "behind the glass" wherein a continual, automatic process gathers real-time sensor data, and datalink-derived data, and performs comparisons to on-board data and databases to evaluate if new hazards in the external environment (e.g., terrain, traffic, weather, or obstacles) have been identified and are emerging as threats to safety. This function will also be used to identify, for example, vehicles that are not equipped with ADS-B or have transponders that have failed. If identified and if they merit the attention of the flight crew, appropriate warnings, cautions, or advisories are provided. The EHM will minimize false alerts and missed detections, meeting, for example, the requirements emerging from RTCA SC-186 for Conflict Detection and Resolution systems (ref: RTCA DO-289).

In the TMA, conflict detection and resolution (CD&R) functions are provided. These CD&R algorithms are an integral part of BTV flight deck technologies as they provide an additional protective safety layer, should the proactive features of the BTV flight deck unforeseeably fail to mitigate hazardous circumstances. The CD&R is tailored to emerging NextGen operational concepts. The CD&R functions merge current TCAS- and ADS-B-based capabilities to increase the altitude range coverage and performance for NextGen operations and also includes a runway incursion detection and surface operations CD&R.

Weather creates continual change in current day operations. Ultimately, NextGen operations should employ a common picture of the weather for all NextGen decision-makers and users with weather integrated directly into sophisticated decision-support capabilities (JPDO, 2008). Given the ten-year out assumption for this ConOps, this comprehensive common picture is not yet realized in the cockpit. Instead, up-linked ground radar and current observations and forecast information (using FIS-B services, for example) – common to flight operations and ANSPs are available to the flight crew. On the flight deck, tactical and strategic weather decisions are made from a piecewise composite weather picture based on these "common" data coming from data link, and on-board weather radar observations and derived products.

The weather radar provides critical real-time sensing. Our NextGen baseline configuration uses an advanced weather radar that produces a three-dimensional (3-D) display of weather from the ground to 60,000 feet out to 320 nautical miles in front of the aircraft with the capability for plan and vertical views for detailed user analysis. The

radar image is no longer dependent upon the knowledge and experience of the user for elevation control - ground returns are automatically extracted using an on-board terrain database and radar elevation changes and scans are automatically controlled and stored to create the 3-D image of the weather.

The radar retains windshear detection and alerting functions and also provides enhanced turbulence detection capabilities.

The weather data sources, on-board and off-board, are integrated and fused to create a single image. Weather trending is provided by pilot-controllable looping of the NextRad-like data combined with onboard sensor data using forecasting. Significant Meteorological Information (Sigmets), Airman's Meteorological Information (Airmets), Pilot Reports (Pireps), and forecasts are annotated to the display.

Information is processed and analyzed with respect to the planned arrival to ensure that Required Times of Arrival (RTAs) are met and runway/arrival planning considers the enroute and airport weather. Recommended arrivals and runway exit alternatives are computed to facilitate operations. The fuel and time costs, as well as the associated RTAs and Estimated Times of Arrival (ETAs) impacts, are also computed.

One host for BTM decision support tools will be the Electronic Flight Bag (EFB).

- The EFB serves as an intermediate agent between the flight deck and the external environment. This device performs a “gate-keeper” function for the crew to intervene and interact with information flowing between the aircraft and the ANSP. For instance, the EFB hosts advanced graphical interfaces and interactive decision support tools to allow the crew to review their proposed or ANSP-proposed routing change requests. The crew uses these high-level tools to gate information from the ANSP to the aircraft or from the aircraft to the ANSP. Once agreeable (i.e., in terms of new trajectory / state changes), the changes are acknowledged, accepted, and executed essentially as they are today. Similarly, the EFB can host performance analysis tools to determine if ANSP-proposed expected taxi clearances and runway exits are “executable” given the current runway conditions and aircraft loading. As an intermediate agent, these powerful “what-if” analysis and decision support tools can be created and employed on the EFB whereas these same or similar capabilities might otherwise be uneconomical or cumbersome to implement within the high-integrity flight deck display and flight management systems.
- Before executing flight procedures, a mission rehearsal tool allows the pilots to rehearse and preview flight path information and routing information in relation to 3-D terrain information unlike paper charts and Navigation Display (ND) map modes. The mission rehearsal tool, in effect, creates a new and much more effective way to conduct landing and take-off pre-briefings. The preview capability would enable flight crews to develop and refine their mental model of the operation, particularly as they review emergency or contingency procedures, such as go-arounds. The planned flight path may be viewed from various

orientations to provide improved path and terrain awareness via graphical 2-dimensional or 3-D perspective display formats. By coupling the path with a terrain database, uncompromising terrain awareness relative to the path and ownship is provided and can be reviewed and the operational procedures can be rehearsed before performing the actual task. By rehearsing a particular mission, check list items are reviewed and coordinated between crew members, terrain, performance, and configuration/procedure awareness can be highlighted, and non-normal procedures can be discussed by the flight crew.

- During en-route operations, a mission rehearsal tool can also serve as the primary conduit by which flight plan negotiations can be made using preview functions. Terrain, traffic and weather with current, planned, and proposed routings are depicted and animated so conflicts and predicaments can be detected and “what-if” scenarios analyzed before acceptance or modifications negotiated. Impacts such as time of arrival and fuel are estimated and displayed for crew consumption.

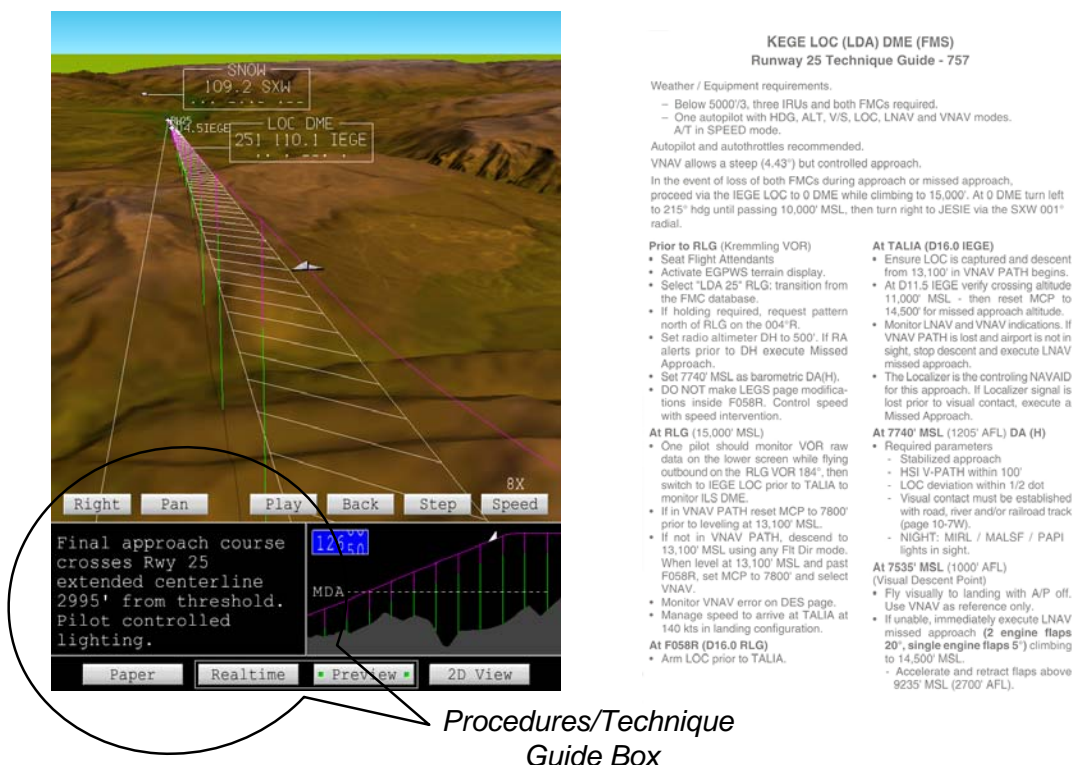


Figure 4: Mission Rehearsal Tool Concept Illustration

3.3.4 Visual Display Enhancements

The information processing functions under the BTV concepts will significantly improve the quality and ensure the integrity of the data. To fulfill the BTV concept objectives, additional display format improvements will be created. These capabilities will be part of the head-up, head-down, and head-worn display suite. These capabilities are part of the decision support role, providing critical situation information to ensure that the flight crew remains fully in-the-loop.

Displays provide EVO capabilities by the combination of EV and SV with sufficient accuracy, integrity and availability to support the operational approval and certification. All-weather operations, down to 300 ft runway visual range, are conducted using this EVO capability without much of today's required airport infrastructure, such as approach lighting systems, surface movement guidance systems, or instrument landing systems. Spatially-integrated visual flight reference information and cues enhance the flight performance and safety such that these low visibility operations are similar to today's VFR flight operations.

Cockpit Display of Traffic information (CDTI) is an integral part of the operational awareness and capability for self-separation or shared separation services under NextGen. CDTI provides one informational component to meet the operational tenets of VFR operations – i.e., self-separation from other traffic and see-to-follow as described in Section 3.4). Intent information is included when necessary and appropriate to augment the surveillance data. The intent information is derived by “snooping” on the broadcast data-link communications and extracting the relevant trajectory-based operational data.

4DT (4-Dimensional Trajectory) operations are the norm. To execute these precisely, the crew is given accurate path information plus trend information with respect to RTA and ETA. Further, intent information for other traffic arriving before ownship is used to build in sufficient awareness of others and their intended route of flight as precaution in the event that contingency procedures are required. By snooping the aircraft intent, ownship will still have to guard for pilot errors or blunders.

The capability of automating the display of uplinked FIS-B information is provided. For example, datalink-provided ATIS information is aurally provided upon request from the flight crew via a conversion of the information to synthesized voice. NOTAM and ATIS-critical information is also automatically parsed and displayed (through visual and aural presentations as necessary and appropriate) from this action, including adding this information to all relevant flight and airport surface maps and primary flight reference displays.

The capability to estimate and display predicted wake vortices is provided during wake-sensitive operations, such as closely-spaced parallel approaches. Estimated vortex positions and movements are computed using methods such as [Holford and Powell, 2003](#). (Once sensor technology has matured, actual wake positional and strength data and movement can be used instead.)

3.3.5 Communicative Interface Enhancements

In the NextGen environment, data-link communications will be emerging as the standard air traffic/ANSP communications interface. However, not all information will be delivered via data message. For this reason, flexible and adaptable communicative interfaces are created.

Data-link communications on the NextGen baseline transform the modality of pilot-ATC communications from aural to visual communications as text read-outs on the instrument displays. This change generally provides positive benefits for pilot-ATC communications (see Kerns, 1991; FAA 1995 and 1996; Lozito et al, 1993; Corwin & McCauley, 1990; and, Talotta et al, 1992):

- The reduction or elimination of message blocking and congestion.
- The persistence of the message.
- Improved information-processing efficiency and accuracy by permitting user-paced communication tasks, elimination of continuous listening workload, and reduction in task interruptions.

Enhancements to this data communications interface are created within this ConOPS to compensate for the deficiencies in this methodology. Data-link may improve one source of miscommunications – the inability to get the message from one party to the other – but it does not necessarily address the rest of the communications process – i.e., whether the message was understood and whether it accurately conveyed the speaker’s intent (Orasanu et al, 1997).

New crew-vehicle interface technologies are introduced herein to identify when the wrong communicative information is being used, generate or enhance situation awareness to the flight crew within a data-link environment, reduce head-down time and workload, and promote the construct of a shared situation awareness between the ANSP and the flight crew.

Auditory and communicative interface technologies will create an “equivalent”, yet improved radio telephony modality within the TMA. These technologies leverage emerging commercial-off-the-shelf speech recognition and “text-to-speech” capabilities to create an equivalent aural interface modality *when desired or required by the operation*.

Effective voice bi-directional systems (synthesis and recognition) are introduced to the flight deck. This work leverages off of mature speech recognition and synthesis methods (e.g., see <http://www.speech.cs.cmu.edu/comp.speech/SpeechLinks.html>) by application-tailoring to the aviation application. Aviation-unique issues being address include the following:

- Extensive use of “spoken” acronyms (e.g., “HUD,” not “H-U-D”)
- Extensive use of “names” to associate geographical locations, such as waypoint identifier names, and flight operations standard operating procedures
- Phonetic alphabet
- Standardized Radio Communications Phraseology and protocol.
- Extensive list of “company” and “manufacturer” names which imply operational and capability constraints (e.g., “Follow Boeing traffic, at your 3 miles and 12 o’clock”)
- Special Use Words (“Expedite”, “Emergency”, “Wilco”, “Roger”)
- Criticality of the speed and accuracy of the communication

- Critical speed and recognition rates (on the order of 10^{-9} -type accuracy error requirements) for verbal communications in Class B airspace.

In a voice-by-exception environment, information processing and voice synthesis are used to recreate intelligent “party-line” information. Instead of a continual stream of ATC-pilot communications, the data-link communications across the airspace are monitored by on-board processing. These communications are parsed for importance to ownship using criteria such as weather, geographic proximity, route of flight, etc. When deemed important, the data-link communications are presented to the flight crew. The communications modality is tailored for criticality – e.g., voice communications used for more urgent data. Textual output of all data-link messages is always available for reference/persistence. Visual display annunciation or data tagging of the messages are available.

During TMA operations and in close-proximity to the responding traffic, aural presentation of messages is used with 3-D audio localization added to provide spatial awareness of the communications. Unique voices are synthesized to improve recognition of the data-link sources (e.g., one voice for traffic-1, another for traffic-2, another voice for tower, approach control, etc.) The text messages are visually linked cockpit displays as well by highlighting or iconic changes. Methods to add stress and urgency in text-to-speech applications are added as appropriate.

In non-datalink, or “redundant voice” operations, speech recognition of radio inputs and read-backs is applied to create textual records for crew review. These data are also parsed to create loadable routes for entry into the Flight Management System (FMS), off-loading the need for manual entry, thus, minimizing head-down time for key-punching. Reception of ANSP instructions and their read-back by the flight crew is used for error correction and error detection – for example, correctness comparison of instruction and read-back.

Future instantiations for this interface include speech recognition for stress and workload identification.

3.4 Modes of operation

BTV flight operations are comprised of three components:

1. Equivalent Visual Operations Capability
2. Enhanced Visual Capability
3. NextGen Operations Capability

These modes are discussed separately but they are, in fact, an integrated flight deck operational capability created by application of the aforementioned operating concepts, technologies, systems and subsystems.

3.4.1 EVO

For the purposes of this ConOps, Equivalent Visual Operations (EVO) are enabled by an electronic means of providing sufficient visibility of the external world and other required flight references on cockpit displays for the flight crew so that the safety, operational tempos, and VFR-like operational procedures of current-day VFR are achievable in all weather conditions. These operations pertain to both airborne and surface operations within the TMA.

In this form of EVO, separation authority is delegated to the flight crew (as it is under VFR), although the flight operation is actively supervised by the ANSP using trajectory-based operational concepts and procedures.

The design of such an EVO capability must be sufficient that separation authority and capability provides for the following:

1. “see-and-avoid”
2. “see-to-follow”
3. “self-navigation”

Visual displays will provide an electronic means of providing sufficient “visibility” (including accuracy, integrity, and availability) of the terrain, airport features, and other required flight references to enable the flight crew to “see-and-avoid,” “see-to-follow,” and “self-navigate.” In addition, these displays will optimally provide this information in an intuitive fashion, analogous to visual flight today, enabling minimal training or transitional impacts from VFR to IFR flight operations. Head-up operation also minimizes any transition from instrument to visual flight conditions, adding another layer of safety within the overall system safety concept. As such, head-up and head-worn displays are critical.

The principle of “See-and-Avoid” is defined under 14 Code of Federal Regulations Part 91.113, *across all classes of airspace*, that “when weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft.” To enable see-and-avoid by an electronic means, a “see-and-avoid” or maybe more appropriately, “sense-and-avoid” must be created which combines on-board sensors and broadcast and datalink communications (e.g., TCAS and ADS-B) to sense the presence of another airborne vehicle and provide sufficient fidelity to allow the pilot (or system) to steer clear. The “BTV” application will dovetail closely with work being performed by the Uninhabited Aerial Vehicle community for “sense-and-avoid” (e.g., see Kuchar, 2004; Drumm, 2004; Schaefer, 2004).

Self-navigation, in this context, includes the ability to identify and safely fly with respect to visual flight references (such as navigation with respect to cultural objects - roads, rivers, large man-made structures, etc) and the ability to safely conduct visual approaches, landings, and take-off operations, without collision with the terrain or obstacles.

“See-to-follow” is a capability - not a regulatory requirement. “See-to-Follow” in present operational context alleviates the controllers’ responsibility to provide vectors for an aircraft under its control. Because the controller is no longer responsible for separation or spacing, the controller workload significantly drops. By acknowledging traffic, the aircraft is now responsible to follow this aircraft in-trail, maintain separation from the lead aircraft, remain clear of clouds, and avoid the wake turbulence from the lead. Under the DDS concept, visual displays will provide sufficient information to perform this function. Merging and spacing tools (e.g., Bone et al, 2003; Baxley et al, 2006), on-board and with the ANSP processes, will stream-line this operation and optimize spacing.

These capabilities are not to imply that displays must replicate the external world references. Instead, these capabilities are designed on the basis of equivalent levels of performance and safety whereby displayed information is an analog of the real-world, with symbolic or imagery augmenting this analog to provide equivalent flight reference information.

3.4.2 EVC

Enhanced Visual Capabilities (EVC) provide the technologies by which the safety of EVO can be enhanced from that of present-day VFR operations. EVC is intended to ensure that BTV operations mitigate the limitations and improve upon the safety of these VFR operations by providing enhanced visual capabilities for the crew so that they may avoid or mitigate hazards which would otherwise be “invisible” to the flight crew. This includes, for example:

- 1) Wake vortices: Prediction is used to show the position, intensity, and drift of wake vortices, especially for wake-critical operations, such as closely spaced parallel approaches. Relative position system information, data link information (ADS-B and FIS-B), and atmospheric data are used for these estimates (e.g., see Holforty and Powell, 2001; Powell, Jennings, and Holforty 2005; Holforty et al, 2003)
- 2) Clear Air Turbulence: winds and automatic Pireps will be used to identify predicted areas of clear air turbulence. Based on certain criteria, this information will be used for crew alerting and avoidance, as necessary and appropriate.
- 3) Wind shear: Wind shear data from on-board weather radar will be displayed given certain criteria such as intensity and location, for alerting and avoidance by the crew.

In addition, unlike current visual arrivals, approach procedures will use vertical path guidance, independent of the actual approach in use. If explicit vertical guidance is not available for the approach procedure, a vertical path profile is constructed and explicitly displayed and used by the flight crew which meets the altitude performance and constraints of the underlying procedure being flown. This procedure enables all approach procedures to follow consistent vertical path guidance with stabilized approach procedure - a key facet to approach and landing accident reduction (Flight Safety Foundation, 2000).

NOTAM information in addition to being part of the pre-flight/pre-approach briefing, will be transmitted via datalink services (e.g. FIS-B), once in range of the TMA and automatically processed to update the flight crew displays. These data will include non-visible items such as: a) taxi-way and runway closures; b) obsolete routes and procedures; c) temporary flight restrictions; and, d) temporary obstacles.

3.4.3 NextGen

NextGen will present several unique challenges on the flight deck. This facet of the concept identifies these challenges and identifies technologies and operating paradigms whereby BTV flight operations are realizable within NextGen.

NextGen is envisioned as a revolutionary approach to air traffic management that requires a dramatic shift in the tasks, roles, and responsibilities for all operators.

- 4DT operations will be the norm. Display information will support these operations and contingency events in the unlikely event that they occur. New concepts, in particular, for 4DT surface operations will be particularly challenging.
- Separation responsibilities will vary depending upon the operation and flight phase. Separation responsibility will range the complete spectra from shared, to solely responsible by the Air Navigation Service Provider or the flight crew. Merging and spacing tools are available to support these roles. Within the TMA, the pilot is assumed to be responsible for separation and spacing.
- Data-link communications will be emerging as the standard interface. Flexible and adaptable communicative interfaces will be needed. Data-link communications is the key principle to a Net-Centric capability thorough NextGen.

The procedures performed by 4DT-capable aircraft, in addition to EVO and EVC operational capabilities, are supported by the BTV technology, include the following:

- 4DT Procedures. In addition to basic RNP capability, aircraft must meet specified timing constraints at designated waypoints along their route. Several levels of 4DT operations exist, defined by the level of navigational and timing constraints. Continuous descent approaches are an example of 4DT procedures.
- Delegated Separation Procedures. The ANSP delegates responsibility to capable aircraft performing the basic 4DT procedures described above to perform specific separation operations using onboard displays and automation support. Examples include passing, crossing, climbing, descending, and turning behind another aircraft. In these operations, the ANSP is responsible for separation from all other traffic while the designated aircraft performs the specific maneuver.

- Airborne Merging and Spacing Procedures. 4DT aircraft are instructed to achieve and maintain a given spacing in time or distance from a designated lead aircraft as defined by an ANSP clearance. Cockpit displays and automation support the aircraft conducting the merging and spacing procedure to enable accurate adherence to the required spacing. Separation responsibility remains with the ANSP.
- Airborne Self-Separation Procedures. Aircraft are required to maintain separation from all other aircraft (and other obstacles or hazards) in the airspace. Aircraft follow the “rules of the road” and avoid any maneuvers that generate immediate conflicts with any other aircraft. Self-separation procedures are conducted only in self-separation airspace. The ANSP provides high-level oversight to safely sequence and schedule aircraft exiting self-separation airspace.
- Low-Visibility Approach and Departure Procedures. Aircraft with appropriate cockpit displays and automation support conduct landings and takeoffs safely in low-visibility conditions without relying on ground-based infrastructure by using onboard navigation, sensing, and display capabilities.
- Super-Density Procedures. Aircraft conduct delegated separation procedures, such as closely-spaced parallel approaches within very precise tolerances for position and timing to maximize runway throughput.
- Surface Procedures. 4DTs may be used on the airport surface at high-density airports to expedite traffic and schedule active runway crossings. Equipped aircraft may perform delegated separation procedures, especially in low-visibility conditions.

4. Operational Scenarios

BTV may apply to all phases of flight to improve a pilot's ability to see objects and features in the surrounding environment and to improve aviation safety by increasing awareness of terrain, airport features, traffic, and obstacles; especially during operations at night and in low visibility conditions. However, only a subset of operations and phases of flight are discussed herein to illustrate the concept.

As previously described, BTV enables VFR-like operations utilizing electronically-derived visual cues as needed. These cues are provided by a "Vision System (VS)." The VS is created such that the flight crew has sufficient flight references regarding the external world independent of the actual weather conditions. The term "Vision System" is used to be "technology agnostic" referring to a system, regardless of source or technology, which provides an electronic means of continuous visual-like information for the pilot/flight crew. For instance, the VS may be created by an enhanced vision system, synthetic vision system, or a combination of both.

To illustrate, an example operational scenario is described for three flight phases:

- 1) *Approach.* The approach flight phase begins at or near a final approach fix (FAF) and continues through Minimum Descent Altitude (MDA) or Decision Altitude (DA)/Decision Height (DH), whichever is applicable, and ends 100 ft above the touchdown zone elevation. BTV enables the aircraft to safely continue from the published MDA or DA/DH to 100 ft above the touchdown zone elevation in weather and visibility conditions which otherwise preclude using natural vision to see the required visual references to continue the descent below the MDA/DA/DH.
- 2) *Landing.* For the landing phase, BTV enables the aircraft to safely descend from the published MDA or DA/DH, whichever is applicable, to land, roll-out, and turn-off the active runway in weather and visibility conditions which otherwise preclude using natural vision to see the required visual references. This phase transitions the flight from the approach (Item #1 above) to the surface phase.
- 3) *Surface Operations.* During surface operations, BTV enables the aircraft to safely operate on the surface, including taxi, parking, and gate operations, in any visibility condition and independent of airport lighting infrastructure at operational tempos associated with current-day VFR. This phase is required for both the landing and take-off phases. However, for this example, the departure phase is not discussed.

This example only considers the flight deck aspects of BTV and is derived in large part from existing guidance material and publications (e.g., FAA Advisory Circular (AC) 120-29, FAA AC120-28, RTCA DO-315). These scenarios do not identify what modifications or improvements, if any, are required in crew training or equipment, procedures, equipment or training associated with ANSPs, or other ground and airport infrastructure or facilities.

Consider the following sequence of events as an example only, illustrating how BTV operations might be conducted under the ConOps described in Section 3.

- (1) Before beginning the approach and conducting operations reliant on BTV capability, all required equipment will be verified as on, if previously off, and built-in test and calibrations, as necessary and appropriate, are conducted. Continual system monitoring and test functions are active to alert the flight crew in the event of failures or malfunctions.
- (2) Merging and spacing operations will have been negotiated with the ANSP and the lead, or paired aircraft has been identified. Display information is provided to ease pilot workload and enhance situation awareness of the approach spacing and threshold Required Time of Arrival. Data-link communications are the norm prior to the FAF, with voice communications only used by exception. After the FAF, voice communications with the ANSP become primary, data link secondary, but active.
- (3) On-board systems are continually monitoring all data-link messaging and radio traffic and processing is used to determine an appropriate form of notification to the flight crew. For example, “urgent” messages may generate visual and aural cues, including a digital synthesized voice call-out. 3D audio localization and tailored voices may be used for additional cueing. Messaging can be screened to create an optimal “party-line” environment, even during a data-link messaging environment, where the data messages are intercepted and if relevant, are communicated to the flight crew. Radio transmissions are similarly screened.
- (4) Prior to the FAF, the 4D surface trajectory, including expected runway exit and taxi route, are communicated from the ANSP to the flight crew via data-link. These data are reviewed by the flight crew, using EFB-enabled review and analysis tools. Negotiations on the runway exit are conducted and concluded prior to the FAF, if necessary. Once agreed upon, the flight crew reviews, accepts and executes these data into the FMS. Mission rehearsal tools are used to review these plans, including autobrake settings, runway surface conditions, runway deceleration profiles, runway exit speeds, and approach speeds calculations. The tool fosters crew interaction to ensure understanding and acceptance.
- (5) The flight crew plans for a published instrument approach procedure, other than Cat II/III, or published visual arrival procedure as per ANSP direction, flight crew direction, or negotiation. EVO procedures, whereby the flight crew may follow another aircraft using equivalent visual flight deck capabilities, may be in effect. A positive means is available to indicate to the flight crew and to the ANSP that a “see-to-follow” operation is in effect and that the proper “see-to-follow” traffic is designated. For EVO procedures, using either “see-to-follow” or a published visual arrival, the flight crew has “see-to-avoid” responsibilities. The flight crew will have appropriate display information to maintain sufficient separation from lead-aircraft or a ‘see-to-

follow' lead and indications of the predicted location and movement of trailing wake vortices to avoid turbulent upsets.

- (6) Relevant NOTAM updates are up-linked and reviewed by the crew prior to the approach. Displays are automatically updated, with significant deviations in procedures, obstacles, or operations, such as closed runways or TFRs, requiring flight crew acknowledgement before they are accepted to ensure the flight crew understands their significance.
- (7) Weather services provided via FIS-B and coupled with on-board sensors/system observations, are used to evaluate the approach weather conditions, runway conditions, braking conditions, and other meteorological conditions.
- (8) The flight crew conducts the briefed approach in accordance with company standard operating procedures. Call-outs and procedures unique to EVO or BTV operations may be used. Under current FARs, the instrument portion of an instrument approach procedure ends at DA/DH or the MDA, and the visual segment begins just below DA/DH or the MDA and continues to the runway.
- (9) The approach to the published DA/MDA, through to the runway, follows a continuous vertical path to promote a stabilized approach procedure. This path may be defined and generated by the instrument approach procedure in use or, if a vertical path is not defined by the instrument approach procedure (i.e., non-precision approach), the BTV or supporting subsystem will define the path and provide guidance to the crew based on this path.
- (10) In the equivalent visual portion of the operation, from DA/DH or MDA down to touchdown, roll-out, and to the gate, the primary reference for maneuvering the airplane is based on what the pilot sees visually through the electronic vision system and any available OTW cues. As such, the required visual references displayed by the electronic vision system (detailed in the following), are continuously and distinctly visible and identifiable by the pilot.
- (11) At DA/DH or prior to the MDA, the pilot makes a decision whether to continue descending below DA/DH or MDA. This decision and the subsequent use of the vision system (VS) is based on the visual information provided OTW in conjunction with information provided by the VS (or other suitable means), the comprehension of its meaning, and the projection of its status in the near future. At DA/DH or prior to the MDA, to continue the descent below the DA/DH or continue beyond the charted Missed Approach Point (MAP) or descend below the MDA, the VS provides information sufficient to:
 - Portray the present descent rate, its status with respect to normal operations and normal maneuvering limits, and provide trend information that the descent rate and aircraft position will allow a safe descent to landing.

- Provide status and trend information that indicates if, with normal maneuvers, a touchdown can occur with acceptable descent rate and within the intended touchdown zone.
 - Indicate to the pilot (crew) that the path toward the intended touchdown point is within that prescribed for the visual segment of the standard instrument approach procedure in use. If possible, the VS will allow verification/identification that the path toward the intended touchdown point is free of all obstacles, charted or otherwise.
- (12) A missed approach/go-around is executed at the DA/DH or the charted MAP or so as to not descend below the MDA if the required equivalent visual references are not visible and distinctly identifiable or if the aircraft is not in a position to land safely. For a missed approach/go-around initiated at or prior to the MAP or at or before descending below the DA/DH, the pilot executes the missed approach procedure in effect for the instrument approach procedure being flown.
- (13) The VS and its associated symbology and flight director-type guidance to aid in awareness of charted obstacles, to track the desired 4D trajectory, and to optimize control and energy management per the reference trajectory. Visual display information is tailored to indicate to the flight crew when TERPS protection from obstacles are provided, and/or when obstacle and terrain clearance is the sole responsibility of the onboard system.
- (14) Throughout the operation, pilot(s) are provided system health status information to support aircrew awareness and to promote proactive mitigation in the event of failures or malfunctions.
- (15) During final approach and landing, the BTV VS provides the crew with sufficient situation information and command information (including guidance) to enable the pilot to (a) maintain the final approach path within required performance criteria, (b) align with the runway, (c) execute the flare maneuver, and (d) land the aircraft. Pilots utilize the BTV VS in conjunction with OTW cues to ensure the safety of the operation.
- (16) Similarly, after touchdown, the BTV VS provides information enabling a safe rollout and runway turn-off at the desired exit without significant lateral deviation from the runway centerline, in nominal and off-nominal conditions, including slippery runways, crosswinds, and engine failure conditions. The BTV VS cues in addition to OTW cues provide pilot(s) with continuous awareness of ground speed, braking performance, runway turn-off locations, taxiway locations, and taxi routes and hold-short locations (as approved by the ANSP), as well as the relationship of the aircraft to centerline and edgeline markings, obstacles, and other aircraft. Tactical guidance (e.g., flight director-like cues), enable pilot(s) to track and to maintain the approved 4D path as well as to reduce the necessary pilot compensation or workload.

- (17) Braking and exiting information is provided symbolically to aid pilots in taking the designated runway exit at an appropriate speed that minimizes runway occupancy time and considers passenger comfort levels.
- (18) The flight crew is aware of braking and runway conditions by the color of the approach, runway and taxi lights and other lighting identify specific portions of the airport and runway, such as the touchdown zone, edge lights, centerline lights and runway remaining markers when natural vision is available out-the-windows for the pilot. These cues are replicated by similar or other intuitively suitable means in the VS displays to supplement or replace these natural vision cues, when not available.
- (19) Upon exiting the active runway, the flight crew has primary responsibility for tactical separation from other traffic and vehicles and control of ownship to comply with the assigned surface route and any hold-short instructions. The BTV concept will also effectively replace the air-side of Surface Movement Guidance System requirements. ANSP ground control will provide oversight for strategic separation and control of surface traffic. However, the flight crew bears primary responsibility for separation and coordination with ground control to ensure their understanding and their ability to meet ownship's taxi route clearances and time-of-arrivals.
- (20) During taxi operations, the primary reference for maneuvering the airplane remains what the pilot sees visually out the windows, but is now also supplemented by what is shown on the VS displays (e.g., graphical depictions of taxi routes, hold-short locations, and gate locations). The VS provides visual cues, in augmentation with the available out-the-window visual cues, for the pilot to maintain their assigned surface route and to ensure separation from other traffic, vehicles, and obstacles.

A HUD, or HWD, is employed for the pilot-flying to maximize eyes-out time. The pilot-not-flying monitors head-down displays in a strategic sense, for example, informing the pilot-flying of upcoming turns, relevant traffic, and RTA performance.
- (21) After landing, if a change to the expected taxi route is necessary (e.g., in the event that the crew (pilot) missed their expected runway exit), an amended taxi clearance is communicated via voice with the ANSP for expediency. Automatic analysis of the radio message and flight crew read-back of the instructions are used to automatically build a taxi route loadable into the FMS. This route is graphically and textually shown on an EFB page for both flight crew members. Once reviewed and corrected, by hand if necessary, the route is loaded on the FMS, reviewed again, and executed as the cleared surface route.
- (22) The flight crew is provided with an automatic method of positive, continual verification of VS performance to support aircrew awareness and to promote proactive mitigation in the event of failures or malfunctions. This includes intuitive displays showing the accuracy of the VS sensed / stored taxi path

against “ground truth.” This information is critical since the error margins for large aircraft surface operations can be small.

- (23) The crew (pilot) receives ground speed and braking cueing sufficient that the aircrew is aware of their operation with respect to speeds that are appropriate to the environmental conditions and the taxiway configuration. Similar guidance is provided for the crew (pilot) to meet their assigned taxi RTA. Similarly, the flight crew is aware of, can establish normal braking, and stop to remain clear of other aircraft that also may be following taxi RTAs or obstacles in all reasonable environmental conditions.
- (24) BTV concepts are designed for improved operations and safety for all phases of flight, but once inside the ramp area (the non-maneuvering area of the airport), the protections and capabilities of the BTV concept cannot be guaranteed.
- (25) During all surface operations, in the (unlikely) event that the BTV pro-active display and interface concepts are not sufficient for maintaining separation, or in the event of other pilot or ANSP errors or blunders, an independent on-board CD&R system provides appropriate levels of indications, alerts, cautions and warnings to ensure separation for traffic or obstacles is maintained at all times. The independent CD&R system serves as a final safety wrapper to ensure safety-of-flight.

5. Concluding Remarks

A Concept of Operations (ConOps) for the Display and Decision Support (DDS) aspects of a flight deck system have been described. This ConOps posits a mid- to far-term solution concept for best supporting human decision making on the flight deck during NextGen terminal area operations.

The ConOps asserts that achieving NextGen's goals requires new technology and procedures – not only on the ground-side – but also in the flight deck. As such, a new flight deck system concept emerges – Better Than Visual (BTV) operations- to achieve the safety and operational benefits promised by NextGen. BTV involves the use an electronic means of providing the pilots with the ability to see objects and features in the surrounding environment and to improve aviation safety by increasing awareness of terrain, airport features, traffic, and obstacles; especially during operations at night and in low visibility conditions. These technologies enable an Equivalent Visual Operations capability whereby Visual Flight Rules-like procedures and operations may be safely and efficiently conducted even when visual 'out-the-window' cues are otherwise obscured by lighting or atmospheric conditions.

Flight deck interfaces and operational concepts are also identified to handle changing communicative processes, driven by emerging net-centric NextGen operations and moving toward datalink-predominant environments. Information processing technologies and techniques are critical. This processing is conducted "behind the glass" to off-load the crew, bringing the crew in the loop only as necessary to alert, notify, or otherwise engage the crew and incorporates concurrent data integrity checking and data extraction/mining functions. Decision support functions assist the flight crew by providing succinct relevant information and attendant guidance to react to and initiate changes as necessary and appropriate.

The ConOps is developed to guide research, development, test and evaluation, using a spiral process, that identify the benefits and barriers to these transformative changes in flight deck displays and decision support functions.

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Appendix A – Assumed NextGen Environment

Background

A NextGen terminal maneuvering area (TMA) environment in the 2020 to 2025, devoid of the benefits from these IIFD/DDS flight deck technologies and a BTV operational capability, is described in the following. This environment is detailed to provide a basis from which to compare and contrast the ConOPS and technologies being developed within the IIFD project.

This environment is derived from concepts developed by the Federal Aviation Administration (FAA) (FAA, 2009). One goal of this NextGen environment is the capability of handling up to 3 times the traffic volume of the present-day (circa 2009) US National Airspace System.

Only TMA operations are discussed since the BTV flight operations focuses on TMA safety and operational benefits.

NextGen Flight Deck “Baseline”

A “NextGen Flight Deck-baseline” is being used to assess the efficacy of DDS technologies. This baseline was chosen since it represents the present state-of-the-art and in all likelihood, will still represent the most technologically advanced commercial flight deck operating in the 2018 time frame. As such, what is known about the current flight deck needs should have been considered and are included in the design of this aircraft. If IIFD technologies can demonstrate safety and performance advantages compared to this baseline, their advantages in use on the remaining NextGen participants will be even greater.

The NextGen Flight Deck-baseline primarily reflects the Boeing 787 aircraft (see Figure A-1).



Figure A- 1: Boeing 787 - "NextGen" Baseline Flight Deck

This flight deck baseline includes the following features:

- Five 9"x12" instrument panel displays, two EFBs, and dual HUDs to support the visual information needs of the flight crew, including five multi-function display areas with cursor control (Figure A-2)
- Airport moving map displays (Figure A-3), enhanced vertical situation displays, integrated approach navigation and navigation performance scales, and (optional) synthetic and enhanced vision systems.
- Navigation and auto-flight capabilities to support RNP 0.1 and Global Position System (GPS) Landing Systems (GLS).
- The Primary Flight Display (Figure A-4) includes provisions for prominent, forward view display of data-link messaging. Automated update of the Flight Management System (FMS) routing via data-link messaging from the ANSP is also provided (not shown).
- Data-link equipment meets Future Air Navigation System (FANS)-1 minimum performance standards as detailed in RTCA DO-305.
- Integrated system alerting and notification is part of the Engine Indication and Crew Alerting System (EICAS).

- The aircraft is equipped with Enhanced Ground Proximity Warning System (E-GPWS) and Traffic Collision Avoidance System (TCAS)

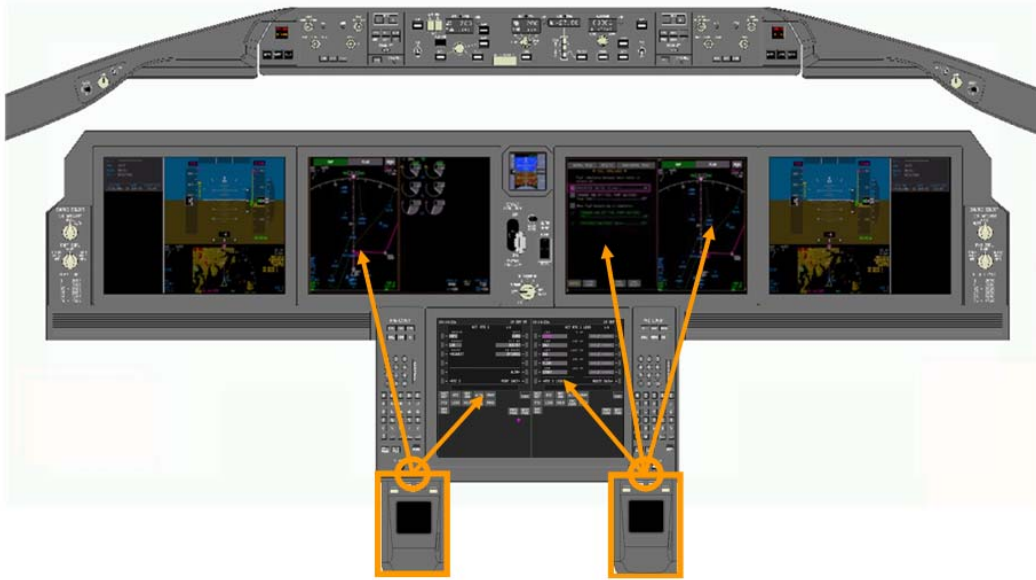


Figure A- 2: NextGen-Baseline Multi-Function Display Layout

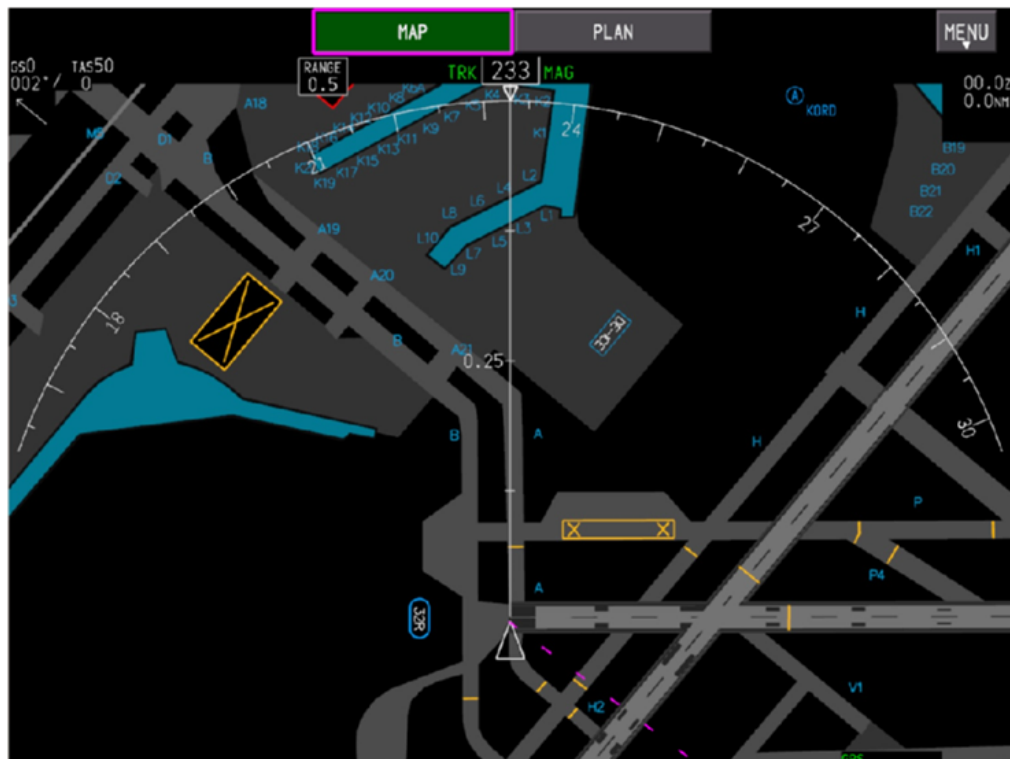


Figure A- 3: Airport Map View - NextGen Baseline



Figure A- 4: Primary Flight Displays - NextGen Baseline

NextGen Operations and Ground Infrastructure (Circa 2020-2025)

TMA modes of operation for the NextGen environment around the Years 2020 to 2025 are described in the following.

Push Back, Taxi, and Departure

Flight plans are delivered and agreed-to via data message prior to push-back.

Significant progress will be made toward taxi clearances being delivered via data message no later than leaving the airport maneuvering area (apron). However, these procedures will still be redundant to voice communications.

Flight deck displays – on forward instrument panel ND and on EFB displays – will portray aircraft movement on a moving map that indicates the aircraft's own position on the airport as well as the position of other aircraft and equipped vehicles in the vicinity.

Departures will be optimally sequenced to maximize throughput into and out of the TMA. Procedures will enable sequencing into trajectory-based flight operations as well

as to balance the optimal utilization of the runway. Position and hold, departure, and take-off times will be metered.

Key ground infrastructure and avionics are identified in Figure A-5 (FAA, 2009).

Push Back, Taxi, and Departure	
Key Ground Infrastructure	Avionics
<ul style="list-style-type: none"> • 4-Dimensional Weather Cube • ADS-B ground stations • Airport Surface Detection Equipment model X (ASDE-X) • Common Automated Radar Terminal System/Standard Terminal Automation Replacement System enhancements • Data Communications • Integrated Departure and Arrival Coordination System • Modernized Aeronautical Information Management System • Surface traffic management decision support tool • System-Wide Information Management (SWIM) • Terminal Flight Data Management System • Traffic Flow Management System 	<ul style="list-style-type: none"> • ADS-B, TIS-B, FIS-B • Data Communications • RNAV/RNP

Figure A- 5: Key Ground Infrastructure and Avionics for NextGen Surface Operations (circa 2020)

Descent and Approach

NextGen capabilities will establish a number of improvements that save fuel, increase predictability, and minimize maneuvers such as holding patterns and delaying vectors (FAA, 2009).

- Enhanced traffic management tools will analyze flights approaching an airport from hundreds of miles away, across the facility boundaries that limit the capability today, and will calculate scheduled arrival times to maximize arrival capacity.
- Information such as proposed arrival time, sequencing and route assignments will be exchanged with the aircraft via a data communications link to negotiate a final flight path. Voice by exception will be the rule in the descent and arrival phase.
- Flights are managed through use of four-dimension trajectories (4DT) that specify accurate current and future aircraft position. These trajectory-based operations – flying precision three-dimensional paths – will provide the capability for integrated arrival and departure operations, using merging and spacing operations.
- Aircraft will fly RNP routing as the norm, rather than the exception, in higher density operating environments. Optimized profile descents, from cruise down to

the runway, will be nominally flown in lower-density operating TMAs, saving time and fuel while reducing noise.

- Metering, controlled time of arrival exchange, and other trajectory-based operations tools are used to increase overall throughput and operator efficiency. These tools also provide more flexibility to utilize the airspace and give controllers better options to manage departure and arrival operations during adverse weather, restoring capacity that is currently lost in inclement conditions.
- Some air carriers will have elected to equip with ADS-B In capability to enable merging and spacing operations such as in-trail oceanic operations and self-spacing and sequencing into selected hubs. Aircraft performing self-separation procedures separate themselves from one another and from aircraft whose separation is managed by the Air Navigation Services Provider (ANSP) without intervention by the ANSP. Unequipped aircraft will be served using separate runways or at off-peak times to avoid conflicts with arriving self-spaced arrival streams.
- Ground-based augmentation systems, particularly in the form of Wide Area Augmentation Systems, will provide the required levels of navigational and surveillance performance and integrity to support these operations.

Flight Information Services-Broadcast (FIS-B) will be in effect (RTCA, 2007). FIS-B will provide automated, timely access to weather and non-control flight advisory information. The information is advisory in nature, for strategic/planning purposes.. FIS-B will provide shared awareness of weather, airspace status, including Temporary Flight Restrictions, and airport operational factors, such as Notices to Airmen (NOTAMS) and automatic Terminal Information Service (ATIS).

FIS products will be used in conjunction with on-board sensing systems, such as Weather radar, for strategic and tactical in-flight decisions and actions by the flight crew.

TIS-B services will also be in effect. The users of TIFS-B include airborne aircraft, aircraft operating on an airport surface, and a select set of airport surface vehicles. The fundamental TIS-B service is to broadcast traffic information to those aircraft and vehicles that cannot adequately obtain it directly via ADS-B.

Key ground infrastructure and avionics to enable NextGen descent and approach operations are identified in Figure 6 (FAA, 2009).

Descent and Approach	
Key Ground Infrastructure	Avionics
<ul style="list-style-type: none"> • 4-Dimensional Weather Cube • ADS-B ground stations • ASDE-X • Common Automated Radar Terminal System/Standard Terminal Automation Replacement System enhancements • Data Communications • Enhanced/Integrated Traffic Management Advisor • Ground-Based Augmentation System • Terminal Flight Data Management System • Traffic Flow Management System 	<ul style="list-style-type: none"> • ADS-B In and Out • Data Communications • FANS • Ground Based Augmentation System (GBAS) avionics • RNAV/RNP • VNAV

Figure A- 6: Key Ground Infrastructure and Avionics for NextGen Descent and Approach

Landing, Taxi, Arrival

Before the flight lands, both the preferred taxiway to be used for exiting the runway and the taxi path to the assigned parking will be available to the flight crew via a data communications link. This message will be sent and received prior to the FAF. It is expected that by the year 2015, 60% of communications will be provided via voice in the TMA, reducing to only 15% by the year 2030 (Eurocontrol, 2005). Voice will still be used for situations which require real-time decision-making and action but routine clearances will be conducted via data-link messaging.

Landing and roll-out operations will be managed through use of 4DT that specify accurate current and future aircraft position. Metering, CTAs, and other TBO tools are used to minimize runway occupancy and maximize flow-thru the TMA.

All approach procedures will use vertical guidance. Satellite-based and ground-based navigation aids are in use, enabling decision heights to 200 ft above touchdown zone elevation. Category II and Category III operations at selected runways and airports will be in effect for decision heights below 200 ft although these operations are restricted to approximately 75 runway ends at 40 airports in the US. Head-up guidance systems and EVS operations enable landing down to 0 ft ceiling and 700 runway visual ranges or 1/8 mile visibility with appropriate equipage. Synthetic vision installed on Head-up displays and EVS equipage on head-down displays enable operations to 100 ft above the touchdown zone elevation.

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